Coastal Lagoon Community and Ecological Monitoring in the Southern Chukchi Sea National Park Units over Five Decades

~ Status and 2012 Field Sampling Report ~

Dr. Martin D. Robards

June 15, 2014

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A report by Wildlife Conservation Society to US National Park Service
Arctic Network – Dr. James Lawler

June 15, 2014

Cooperative Ecosystem Studies Unit Agreement #:

Cover Photo:

WCS/NPS camp at Ikpek Lagoon with Eric Sieh providing logistic support. Photo by Martin Robards.

EXECUTIVE SUMMARY

Wildlife Conservation Society (WCS) provided their first year of assistance to the National Park Service with the design and implementation of the Coastal Lagoon Vital Sign component of the Inventory and Monitoring Program. Our 2012 field effort assessed a) the feasibility of implementing a focused portion of the recommendations from the 2010 Draft Protocol for the Arctic Coastal Lagoon Vital Sign Monitoring Protocol at Cape Krusenstern National Monument (Reynolds and Clough, 2010), and b) adding coverage of the Lagoon Vital Sign to Bering Land Bridge National Preserve. The 2012 Coastal Lagoon Vital Sign monitoring effort explicitly addressed the logistical issues raised in the draft protocol. Earlier Vital Sign efforts were challenged using ground access (4-wheelers) due to impassable outflow channels, leading to underachievement on protocol implementation, and the suggestion that floatplane access may be a more viable way of supporting long-term monitoring.

Between July 21st and July 29th 2012, a four-person crew from the Wildlife Conservation Society and the National Park Service successfully utilized a Cessna 185 on floats to access Ikpek and Cowpack lagoons in Bering Land Bridge National Preserve, and Kotlik, Krusenstern, and Aqulaaq lagoons in Cape Krusenstern National Monument. Over two days at each lagoon (one day at Aqalaaq Lagoon), we used a small inflatable boat equipped with a 9 horsepower motor to visit four long-term (Center, Outflow, Inflow, and Adjacent-to-the-Ocean stations) and three Random stations in each lagoon. At each station, we collected (or attempted to collect) data on physical water parameters (sonde instrumentation), chorophyll a (filtered samples and lab spectrographic analysis), benthic invertebrates (Ponar grab), nearshore fish (beach seine), pelagic fish (gillnet), and opportunistic observations of the avian community.

Results from prior sampling efforts in 1979/1980 (Raymond et al., 1984); 1982/1983 (Dames and Moore, 1983 – and reports therein); 2003/2004 (Reynolds, 2012); and 2009 (Reynolds and Clough, 2010) were synthesized, placed in a single file (excel) for the first time, and are presented here with new results from 2012. Collectively, we are using these field efforts to: a) provide a summary of reference conditions in the lagoons of Cape Krusenstern and Bering Land Bridge National Park Units; b) continue development of the Vital Sign Monitoring Protocol, c) frame more in-depth assessments to place long-term monitoring in the context of seasonal variability, d) initiate new fisheries research in collaboration with the Native Village of Kotzebue to better understand the management needs for whitefish in these coastal lagoons, and e) begin to assess prioritization of coastal lagoons for protection from oil spills based on their ecological or subsistence contribution.

Recommendations for Vital Sign Monitoring Plan

The greatest challenge when establishing which variables to monitor in coastal lagoons is the profound variability of these environments. Based on our experience and prior reports, turbidity can double in one day based on wind alone; temperature of waters that are only a few feet deep, and sit over dark substrate, is easily affected by sun on long clear summer days; salinity varies from almost fresh at inlets to fully marine at outlets (and is reflected in the biotic community); variability in depth and physical water parameters are driven by winds and tides; and seasonality of anadromous fish presence means that even a week can result in markedly different catch results. Only over time will the relative variability of physical and biotic components in different lagoons be understood; and the effects the range and variability of key physical variables has on biotic communities.

The NPS Vital Signs are intended to provide information of value for managers as they seek to understand and respond to long-term changes in the health or condition of resources within National Park units. "The first step in monitoring changes and trends is an inventory of the resources present…the inventory establishes the point of departure for required monitoring activities" (NPS-75, 3). To ensure that the Vital Sign effort is of value to managers, Oakley et al. (2003) recommended a focus on a few key themes that represent what are likely to be topics of long-term interest for this area. While a vital sign should be sensitive to a wide array of themes, the following three provide focus to subsequent efforts in coastal lagoons, and require a base set of variables that would address a wide array of contemporary and future management questions:

1. Climate Change (e.g. storm erosion or deposition)
2. Direct interactions between lagoons and people (e.g., subsistence fisheries or habitat modification)
3. Indirect interactions between lagoons and people (e.g., pollution from oil spills)

The Vital Sign should be able to detect changes as a result of these drivers (climate, direct and indirect human interactions) and provide opportunities to establish which mechanisms lead to the observed changes. With that in mind, **we recommend at least the following twelve variables be considered for further development as part of any long-term protocol for the lagoons** (noting significant cross-over between these recommendations and those of Reynolds, 2012). We emphasize that for recommendations 5, 6, 7, 8, 9 and 11, focused seasonal data from a sub-set of lagoons, or a single lagoon, would provide data of greater long-term value than a single annual sampling of multiple lagoons. With past efforts already providing a general understanding of the lagoon environments in this area (usually through a single annual sample), it is critical that further efforts address seasonality in order to advance knowledge and the value of results to managers. As Houghton and Erikson (1983) cautioned after their relatively comprehensive spatial coverage of coastal lagoons in 1982, the "limited amount of [temporal] sampling makes it difficult to make generalizations."

1. Dynamics of connectivity with marine environment

Documenting annual breaching and formation of beach barriers between lagoons and the marine environment will provide insights into opportunities for fish ingress and egress from the lagoons, as well as help explain variability of physical conditions.

2. Physical lagoon dynamics

Lagoon habitats are dependent on the physical characteristics of the lagoon, and subject to the annual changes that occur, and will occur over time with changing climate. Documenting and understanding lagoon physical dynamics over time is extremely important to understanding the *biological integrity of the system. Bathymetry affects currents and wave propagation within the lagoons. With sea ice coming later in the winter season, the lagoons and coasts are subject to greater impact (erosion) from late season storms, primarily from wave action, with currents transporting the sediments within, and exporting from, the lagoon system. Analysis of geomorphology of lagoon coasts indicates a changing flow environment. How these changes to the physical environment continue to develop with changing climate is important for understanding biological change.*

3. **Overwintering habitat**
Winter ecology of lagoons and its effect on summer biotic communities, including for subsistence fisheries, is likely a function of the availability of overwintering habitat (water under ice). For example, die-offs of nine-spine stickleback in Port Lagoon in the 1980s (Dames and Moore, 1983) were attributed to harsh winter conditions. As a first step to understanding overwintering ecology (and of great help to understanding summer habitat), the bathymetry of lagoons should be established, and next, the relation of water depth to freeze-up of the water column.

4. **Timing of break-up**
Spring bloom likely follows break-up of ice and will be a key driver of productivity. This variable ties to climate change and availability of habitat for fish. Dames and Moore (1983) note that potentially large numbers of anadromous fish leave lagoons during the earliest part of break-up while still under the ice.

5. **Seasonal Water Chemistry and Chlorophyll a (or PAR)**
Providing seasonal baseline conditions in the lagoons is essential. As part of this effort, establishing if electronic PAR values rather than lab based spectroscopy of chlorophyll is possible would provide numerous benefits due to time costs for processing spectrographic chlorophyll samples in the field and long-term monetary costs of sending samples to a lab.

6. **Seasonal phytoplankton composition and abundance**
Phytoplankton are the base of the food web in the arctic, and a significant component of primary productivity to the lagoon and coastal systems. Phytoplankton communities change with respect to seasonal timing, nutrient availability, and water chemistry. It is expected that phytoplankton community composition will change with climate and potentially ocean acidification,

7. **Seasonal zooplankton composition and abundance**
Reynolds (2012) provided some baseline information on abundance of key groups of zooplankton (e.g., copepods), but community composition (and temporal/spatial variability) has yet to be established which may well be a good indicator of long-term changes in the lagoon ecology.

8. **Seasonal epifaunal composition and relative abundance**
Dames and Moore (1983) provide information about the Port and Ipiavik lagoons in the early 1980s. Building from their initial studies, such as those for zooplankton, would provide important information on long-term changes in community composition. Current work by Roy Churchwell

(UAF) could also be used to inform a study plan, particularly for those studying coastal shorebird use of the lagoons.

9. Seasonal fish composition and patterns of use (i.e., resident vs. migratory usage)
Data on fish composition will provide indications of long-term changes in lagoon conditions, the prevalence of invasive species as climate or shipping activities alter fish community dynamics, and the value of specific lagoons as critical feeding habitat for piscivorous species (e.g., Arctic terns) and subsistence fishermen.

10. Fish growth rates (from otoliths) for resident (e.g., starry flounder) and migratory species (e.g., whitefish, herring)
Long-term growth rates of fish could be used to integrate lagoon primary and secondary productivity, particularly for any species that are found to remain in lagoons over winter.

11. Seasonal fish diet sampling for resident (starry flounder) and migratory species (whitefish, herring).

Diet sampling of fish establishes relative abundance of prey species of value to key fish species, and linked with work on zooplankton (recommendation 5) and epibenthos (recommendation 6) would provide the basis to build trophic models for the lagoon biotic community.

12. PolyAromatic Hydrocarbons (PAHs)
In the event of a spill in the region, cleanup end points could include PAH concentrations in local fish stocks.

Recommended Additional Projects in Conjunction with Lagoon Monitoring

While avian work is beyond the scope of the lagoon vital sign, we recommend setting up at least one study plot at each lagoon and a standard protocol for assessment of all avifauna by crews visiting lagoons.

Avian work could dovetail with the lagoon vital sign by adding an invertebrate sampling component during the July – September period in connection with fall-staging shorebird migrants. Such sampling would build from prior efforts in the region at Krusenstern Lagoon (Connors and Connors, 1982) or at Ipiavik and Port Lagoons (Dames and Moore, 1983a,b).

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INTRODUCTION

National Park Managers are directed by federal law and National Park Service policies and guidance to know the status and trends in the condition of natural resources under their stewardship in order to fulfill the NPS mission of conserving parks unimpaired. The 2006 NPS Management Policies specifically directs the NPS to inventory and monitor natural systems. NPS has used the term "vital signs monitoring" since the early 1980s to refer to a relatively small set of information-rich attributes. This subset of physical, chemical, and biological elements and processes of park ecosystems are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values. Vital signs can provide managers with an early warning of situations that require intervention in National Parks. The mission of the National Park Service's Arctic Network (ARCN) Inventory and Monitoring Program includes monitoring 28 specific vital signs in the five northern Alaska park units, including the coastal lagoons of Cape Krusenstern and Bering Land Bridge (Lawler et al., 2009).

In 2007, the Arctic Network Inventory and Monitoring Program began developing a monitoring protocol for coastal lagoons located in Cape Krusenstern National Monument. Using monitoring data to inform management decisions is clearly outlined in both the General Management Plan (GMP) for Cape Krusenstern National Monument (NPS, 1986a): "…monitoring will be conducted so that thorough information about the condition of resources will be available to monument managers," and Bering Land Bridge National Preserve (NPS, 1986b) which notes the: "positive effects on natural and cultural resources within the preserve as a result of natural resource research and monitoring." More specifically, the Cape Krusenstern National Monument GMP states the importance of monitoring water quality within the monument, The National Park Service will establish a monitoring program: "…to provide baseline data on water quality of the monument against which future sampling can be compared."

The coastal lagoons of the NPS Arctic Network represent a critically important ecosystem in the region, and are vulnerable to both climatic change and development impacts. Lagoon Vital Sign efforts address the need for baseline information about the structure and function of lagoons, as well as the dearth of information about the local fish resources utilized for subsistence (Lentz et al. 2001). Without a clear understanding of baseline conditions in the lagoons, including the seasonality and inter-annual variability of physical and biotic components, it is impossible for managers to detect long-term changes that result from climate change, to quantify the impacts of accidents, or develop appropriate management plans (including prioritization of sites) that protect the key functions that these lagoons have on local ecosystems and subsistence economies.

Coastal Lagoons in Northern Alaska

Work in the coastal lagoons of Cape Krusenstern National Monument and Bering Land Bridge National Preserve will eventually be placed in the context of similar work on the northern Chukchi and Beaufort Sea coastlines where the composition and spatial and temporal dynamics of coastal fish assemblages have been relatively well described (e.g., Jarvela and Thorsteinson, 1999; Johnson et al., 2010). Common to all the more northern studies is the significant interannual, seasonal, and geographical differences in physical conditions and fish catches. Lagoon conditions can vary from fresh to saline, sometimes within a season dependent on connectivity (or loss of it) with the ocean. Jarvela and Thorsteinson (1999) found Arctic cod, capelin, and liparids to be the most abundant marine fishes in catches, while arctic cisco was the only abundant diadromous freshwater species. Johnson et al. (2010) found capelin, Arctic cod, juvenile pricklebacks and juvenile sculpins to be the most common taxa in the Beaufort Sea around Cooper Island. In Elson Lagoon, least cisco and juvenile sculpins were most common. Johnson et al. (2010) also concluded that species occupying coastal waters remained relatively unchanged over the past 25 years. Currently, Kevin Boswell, Brenda Norcross, Ron Heintz and colleagues are in the middle of a multi-year project funded by North Pacific Research Board ($1.1 million) looking at fish species composition and physical conditions? in Kasegaluk lagoon and Peard Bay.

Between the North Slope efforts and the National Park Service units, the most significant lagoon research efforts have been between Kivalina and Cape Thompson in the 1950s (Willimovsky and Wolfe, 1966).

Within the focal National Park Service land units, there are seven coastal lagoons described within the boundary of Cape Krusenstern National Monument – Akulaaq, Imik, Ipiavik, Kotlik, Krusenstern, Port, and Sisualik; and four coastal lagoons within the boundary of Bering Land Bridge National Preserve – Espenberg, Cowpack, Shishmaref, and Ikpek. We note that Sisualik and Espenberg may not fulfill all the requirements of being classed as lagoons.

Villages in proximity to Cape Krusenstern National Monument include the Native villages of Kivalina (17 km northwest of the monument boundary), Noatak (13 km east of the monument boundary), and Kotzebue (15 km southeast of the monument boundary). For Bering Land Bridge National Preserve, proximal villages include the Native villages of Deering (20 km east of the preserve boundary), Shishmaref (surrounded by the preserve at a distance of about 20-30 km), and Wales (36 km southwest of the preserve boundary). Many residents of these villages utilize camps along the coastline, including around several of these lagoons. Red Dog Mine, one of the world's largest lead and zinc mines is located just north of Cape Krusenstern National Monument's boundary.

Of the lagoons in Cape Krusenstern, Port Lagoon is the smallest (2 km^2) and Krusenstern Lagoon is the largest (56 km^2). Lagoons vary in the amount of water exchange occurring with the surrounding marine environment. Akulaaq, Krusenstern, and Sisualik are connected to Kotzebue Sound and Imik, Ipiavik, Kotlik, and Port are connected to Chukchi Sea. Akulaaq, Imik, Kotlik, and Port are all intermittently open. Krusenstern Lagoon is seasonally closed at the mouth of the Tukrok River, although this connection with the marine environment is still 15 km away from the lagoon itself. The mouth of the Tukrok is opened in springtime as a result of ice breakup and the pushing of the ice down the river and out to the ocean. The mouth is closed in mid-July as gravel is pushed up by strong wave action resulting from strong storms. Sisualik and Ipiavik are open year-round.

Table 1. Lagoon size, general salinity, and water exchange for southern Chukchi Sea lagoons (ordered north to south). Data from Reynolds, 2012; Blaylock and Houghton, 1983; Current Study.

NPS Unit	Lagoon	Size (km^2)§	Physical Tendency*	Connection
CAKR	Ipiavik	14	Fresh/Brackish	Open Channel
	Port	2	Fresh	Closed
	Imik	5	?	Intermittently Open
	Kotlik	24	Brackish	Intermittently Open
	Krusenstern	56	Fresh	Seasonally-Closed
	Akulaaq	9	Fresh	Intermittently Open
	Sisualik	34	Fresh	Open
BELA	Espenberg	12	?	Open
	Cowpack	109	Brackish	Open Channel
	Shishmaref	370	?	Open
	Ikpek	128	Brackish	Open Channel

§We recognize the subjectivity in describing boundaries– our estimates delineate the main water body (for example not including the long channel connecting Krusenstern Lagoon to the ocean).

*Based on average salinity within lagoon: <11 fresh; >11 - <30 brackish; >30 marine (see Table 3)

Prior Coastal Lagoon Research in ARCN National Park Units

1970-1979

Connors and Connors (1982) described shorebirds and other bird use of Krusenstern lagoon, as well as numbers of Aleutian and Arctic tern colonies in Cape Krusenstern and Bering Land Bridge National Park Units. Connors and Risebrough (1977,1978) provided details of surface plankton tows from this predominantly avian study. They found less diversity of zooplankton species inside, rather than outside of the lagoons in 1977, with Calanoid copepods and Mysids (Boreomysis sp.) reported. Johnson (1966) had earlier found in their study of seven lagoons to the north of the National Park units that lagoons were “ecologically dissimilar” in their composition of zooplankton, although generally including a dominant mix of freshwater and brackish forms.

1980-1989

Raymond et al. (1984) reported basic physical data (temperature, salinity) along with fish and invertebrate composition during 1979 and 1980 along the marine coast of Kotzebue Sound, but included some sites within Sisualik Lagoon (their sites 6,7,35,36,37,40,46,72) and in the Tukrok River linking Krusenstern Lagoon to the ocean (their sites 49,50).

Dames and Moore (1983) and various sub-reports within this document (including Blaylock and Erikson, 1983) as well as the Supplemental Sampling Effort reports (including Blaylock and Houghton, 1983) document the 1982 and 1983 field seasons, respectively, and are associated with the Red Dog environmental studies program. Parameters of relevance to the lagoon Vital Sign monitoring (other chapters include avifauna, vegetation, terrestrial mammals etc.) include physical parameters, epibenthic and infaunal communities, and fish. Sampled lagoons included Port and Ipiavik within CAKR, but also Imikruk just to the north, and Singoalik and Pusigrak Lagoons north of Kivalina. While these latter lagoons are outside of the current NPS study area, they offer potential opportunities for long-term comparative work as they were investigated for zooplankton in the late 1950s and early 1960s (e.g., Johnson, 1966; Tash, 1971; Tash and Armitage, 1967). Lagoon epibenthos were highly variable and attributed to specific lagoon assemblages, timing, and location within lagoons by Blaylock and Erikson (1983). These authors noted a predominance of insect larvae on the landward side of lagoons (primarily Chironomidae), and crustaceans, such as isopods and mysids, in samples from the seaward side of lagoons (Table 2).

Two sampling efforts in three lagoons were conducted for fish in 1982 and reported in Blaylock and Erikson (1983) – Ipiavik (June 28 and July 22, 1982), Port (June 30 and August 30, 1982), and Imik (June 30 and July 25, 1982). Similarly in 1983 two sample periods were reported– June 9-21 and July 11-20. Two beach seine replicates were made at each shoreline lagoons station during June. The beach seine measured 15 m with 1 cm bar mesh wings tapering to a 3-m bag of 0.3 cm bar mesh. In addition, gill nets (1 m by 8 m variable (1 to 5 cm) bar mesh gill nets) were placed at each shoreline lagoon station, perpendicular to shore. Reports include abundance of catches and size of fish.

Results from the Dames and Moore efforts suggested that open lagoons in vicinity of the Red Dog Port Site (Ipiavik and Singoalik) had greater fish species diversity than closed lagoons (Imikruk, Port, and Pusigrak). Ninespine stickleback (*Pungitius pungitius*) were present at 53% of the stations for the five lagoons they studied and this was the most abundant species in all lagoons except Singoalik Lagoon. Alaska blackfish (*Dallia pectoralis)* was only collected in Imikruk Lagoon (located just north of the northern boundary of CAKR). No infaunal species were collected in any of the sampled lagoons, although Blaylock and Erikson (1983) reported work by others that collected nematodes and oligochaetes in infaunal grabs.

With respect to potential effects of winter conditions, Port Lagoon was sampled in 1982 (Dames and Moore, 1983) and numerous 9-spine sticklebacks were collected. Winter conditions leading to freezing of water to the bottom of the lagoon were thought to kill a large number of fish during winter of 1982/1983 with only juvenile sticklebacks found in epibenthic samples during summer 1983, and only dead adults collected by seine (Blaylock and Houghton 1983).

Table 2. Density of lagoon epibenthos and percent composition of abundant organisms. Adapted from Blaylock and Erikson (1983).

Lagoon	Date	Mean Density (#/m2)	Dominant Organisms (% total)
Imik – landward shoreline	7/22/82	4.4	Bivalves (54.5)
			Insect larvae (19.9)
			Isopods (17.2)
Imik – seaward shoreline	6/30/82	22.6	Isopods (50.5)
			Gastropods (27.2)
			Oligochaeta (14.1)
Ipiavik – near mouth of New Heart Creek	7/22/82	5.96	Mysids (75.0)
			Insect larvae (12.1)
Ipiavik – seaward shoreline	6/30/82	0.4	Mysids (60.0)
			Amphipods (40.0)
Port Lagoon	6/30/82	19.8	Isopods (47.6)
			Insect larvae (24.6)
Port Lagoon	8/30/82	3.1	Ninespine stickleback (88.4)
			Insect larvae (11.5)

1990-1999

Schizas and Shirley (1994) investigated Krusenstern Lagoon in 1992. Among their findings was a new species of harpacticoid copepod (*Onychocamptus krusensterni*). This study was in conjunction with a larger survey or benthic and epibenthic invertebrates of lagoons in Cape Krusenstern, but results of the larger survey have not been located yet.

2000-2009

Reynolds et al. (2005) conducted physicochemical (including nutrients) and biological (zooplankton, epibenthos, and fish) sampling in five of the seven coastal lagoons located in CAKR (Imik, Kotlik, Krusenstern, Aqulaaq, and Sisualik) during 7 sampling periods between January 2003 and August 2004. (January 2003; April 2003; July 2003; September 2003; January 2004; April 2004; September 2004). The results of this study were the basis for her PhD dissertation (Reynolds, 2012). However, determining the general status and trends in conditions for these lagoons, in a manner comparable with future years was not feasible; leaving Reynolds to acknowledge that the missing baseline data (e.g., to fully understand seasonality) for coastal lagoons (in Cape Krusenstern) should be a priority for understanding future development or climate change impacts (Reynolds, 2012).

Reynolds' efforts in 2003/2004 were followed up with a more limited sampling effort for the Cape Krusenstern National Monument Lagoons between July 22 and July 28, 2009 (Reynolds and Clough, 2010). During what Reynolds indicates as “pilot sampling”, some of the sampling stations in the Reynolds et al. (2005) study were resampled at Kotlik (only one site), Krusenstern, and Aqulaaq (Reynolds and Clough, 2010). Utilizing the existing sampling sites was intended to allow the data collected by Reynolds et al. (2005) to act as additional baseline information.

During 2009, Reynolds sought to monitor coastal lagoons of Cape Krusenstern National Monument to document the long-term status and trends of physical, chemical, and biological components. In order to achieve that objective, Reynolds planned to collect: 1) physicochemical data in the five lagoons, 2) nutrient and chlorophyll a samples in five lagoons, 3) zooplankton samples in five lagoons, 4) benthic samples in three lagoons (Kotlik, Krusenstern, and Sisualik), 5) pelagic fish species in three lagoons (Kotlik, Krusenstern, and Sisualik), and 6) geomorphological data in five lagoons. These data, along with those previously collected (Reynolds et al. 2005), were intended to provide baseline water quality and species data for the five coastal lagoons in CAKR, more information on parameter variance, data for trend analysis, and to facilitate ongoing development of a long-term monitoring protocol and standard operating procedures for the coastal lagoons vital sign. For this last objective, Reynolds also tested field-sampling methods to determine their feasibility for long-term sampling of these remote lagoon ecosystems.

The following core water quality parameters were collected as required for monitoring as prescribed by the Water Resources Division, National Park Service (Roman et al. 2003): water temperature (°C), dissolved oxygen (mg/L), pH (pH units), conductivity (mS/cm), and salinity (psu). In addition to this suite of parameters, Reynolds (2010) included water depth, water clarity (Secchi disk), chlorophyll a, total nitrogen, dissolved nitrogen, and total phosphorus. Reynolds (2012) found the dominant zooplankton taxa in all the lagoons were copepods and cladocerans. She also collected some fish in a limited gill net and seine effort. The beach seine was hauled one time, in one location, in Krusenstern Lagoon. The 5-panel experimental gill net was set three times, for one hour per set, at three different locations in Krusenstern Lagoon. Geomorphological data (including aerial imagery) were intended to include surface area, shoreline length, and bathymetry, but were not completed.

Overall Picture of Lagoons

Reynolds’ efforts to seasonally sample multiple lagoons were ambitious given their remote nature and profound variability. While providing some valuable baseline data on basic conditions, a greater focus is still needed on a few lagoons to better understand temporal and spatial variability. We do not currently have enough data for reliable conclusions about seasonal or interannual variability, particularly for lagoons only sampled once. Furthermore, while Blaylock and Houghton (1983) note that a week alone is enough to profoundly alter fish composition, Reynolds bins her data by month (with some data also being used outside of the monthly bin, including the July Aqulaaq and September Sisualik samples, which are from August and October, respectively). Consequently, repeat samples of the same lagoon in subsequent years are not readily comparable. Finally, Reynolds neither measured, nor counted most of the fish she caught, limiting any conclusions outside of presence/absence.

Reynolds’ protocols were not fully operationalized, in part due to the challenging logistics of visiting multiple coastal lagoons and conducting statistically sound monitoring activities. Efforts to conduct monitoring using terrestrial transportation were thwarted by impassable river outlets, creating a need and opportunity for NPS and Wildlife Conservation Society to now collaborate towards common objectives and derive mutual benefit. **The end product of this collaboration, beginning with the 2012 field effort (described below) is intended to lead to an updated implementation protocol for monitoring efforts in coastal lagoons, and suggestions for further more in-depth research.** This protocol and recommendations are being developed with the intent of being beneficial for land management agencies. For example, lagoons and their marsh areas are particularly sensitive to climate change or oil that once entrained in the lagoon system would be very difficult to remediate; so, assessing the ecological or subsistence value of different lagoons would support both understanding of change in lagoons as well as contingency planning in the case of an oil spill. As Boswell et al. (2012) state for lagoons on the North Chukchi Sea coast: “Developing a firm understanding of the value and role of these sensitive habitats with respect to fisheries productivity in the Arctic and their function as sources of nutrition and refuge for important fish, birds and mammals is imperative, especially in context of climate and environmental change.”

2012 FIELD EFFORT

Objectives

The objectives of the Wildlife Conservation Society-led activities in 2012 included the following tasks:

1. Update the sampling objectives for coastal lagoons (Reynolds, 2010) to reflect a two-week sampling window using air transportation to accomplish logistics;
2. Provide updated field protocols for the 2012 field season;
3. Oversee logistics and field operations for the 2012 field season (7/17/2012 to 8/2/2012);
4. Collect data at 8 sampling locations from 3 lagoons in Cape Krusenstern – Ipiavik, Krusenstern, Sisualik (Figure 1) and 2 lagoons in Bering Land Bridge – Ikpek, Cowpack (Figure 2). Data will include:
   a. Physical: comparison to prior photographs, connectivity to ocean;
   b. Water attributes: pH, Temperature, Salinity, Chlorophyll a, Total Dissolved Solids;
   c. Biotic: species composition of a) zooplankton, b) fish, and c) macro-invertebrates.
5. Provide guidance for future field efforts within coastal lagoons of ARCN;
6. Prepare a report to communicate results and recommendations.

All objectives have been met except for the photographic comparisons noted in Task 4a. The ShoreZone project is collecting high-resolution coastal data for this area during 2012 and their effort will far surpassed what would be possible with this effort. Their results should be made available to National Park Service when complete.

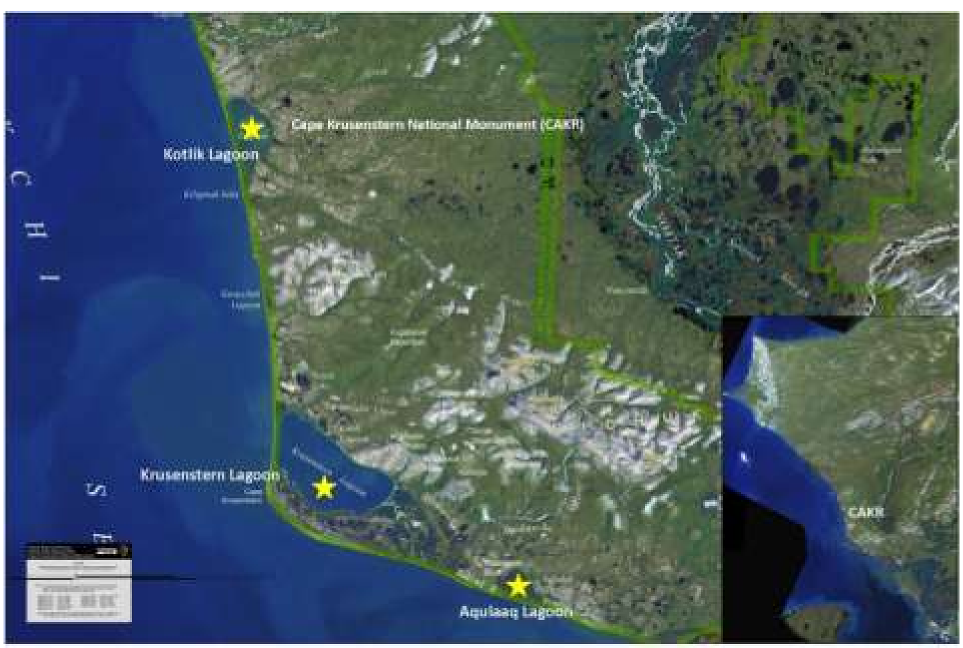

Figure 1. Lagoons sampled in Cape Krusenstern National Monument

Figure 2. Lagoons sampled in Bering Land Bridge National Preserve

Study Design

We built our sampling design based on Reynolds' prior work (Reynolds et al., 2005; Reynolds, 2012). Her sampling sites were based on the work of Blaylock and Houghton (1983): Four of Reynolds' criteria were used for choosing sampling locations: 1) on the shoreline-side of the lagoon (what we term "Marine Edge"); 2) in the middle of the lagoon (what we term "Central"); 3) near creek and river inlets (what we term "Inflow"); 4) at outlets (what we term "Outflow"); and 5) near any known anomalies such as springs (we did not include this designation as most lagoons could be designated with some unique feature). We also added 3 randomly chosen sites in each lagoon to facilitate statistical inference of results over time (Figure 3).

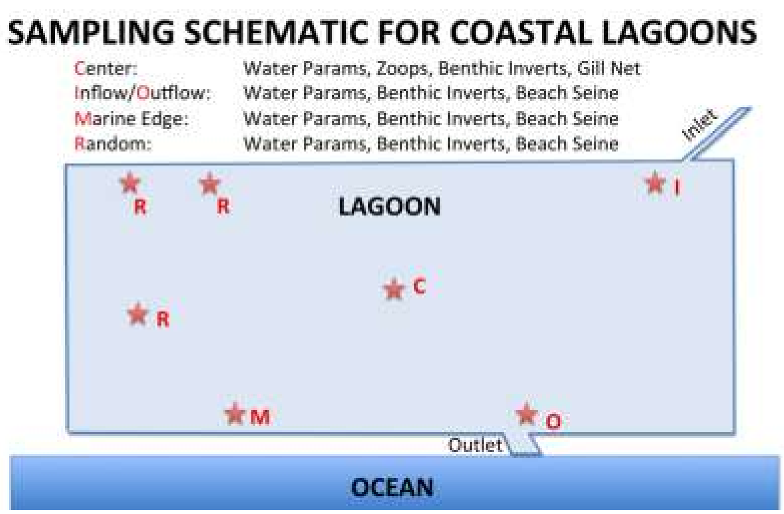

Figure 3. Sampling Strategy for Coastal Lagoon Monitoring (2012)

Field Methods

Water Quality

Sampling methods used to collect physicochemical data were based on the Environmental Protection Agency (EPA) National Coastal Assessment Field Operations Manual (U.S. EPA 2001). At each sampling point and at a depth of 50 cm, the following core water quality parameters were measured in situ using a YSI Sonde multiparameter probe: water temperature, pH, conductivity, and dissolved oxygen. Water depth was measured with a hand-held depth sounder. We did not repeat Reynolds' use of a Secchi disk for water clarity due to the shallow nature of these lagoons and the unattainable precision that would be needed for comparisons across sites and years.

Primary Production

One-liter water samples for Chlorophyll a analysis were filtered within 4 hours of sampling under low light through glass-fiber filters (GF/F). Glass fiber filters were wrapped in aluminum foil and kept as cold as possible in the field (against ice), and stored fully frozen within 24 hours of collection in Kotzebue (returned with pilot). After the field effort, they were delivered to Analytica Inc. a commercial lab. Three one-liter replicate filtrations were processed from each sampling location and the mean reported.

We did not measure nutrients during this effort, recognizing that temporal variability should be addressed in a separate study that seeks to better understand dynamics between nutrients, phytoplankton, and zooplankton. Without such prior knowledge, the costs and effort involved in a single sample were not warranted.

Benthic Community

We attempted to collect benthic macroinvertebrate samples at established water quality sampling sites in all lagoons. Three replicates were attempted at each sampling location with a petite ponar grab. Samples were sieved through a 500µm sieve over the side of the boat and visually assessed. At almost all sites, the petite ponar was unable to collect repeatable replicate samples (sometimes no samples were collected at all due to the hard substrate or due to the drift of the grab in the water column preventing a vertical alignment). Consequently, while we identified numbers of key taxa, we did not return samples to a laboratory for more detailed analysis. Further study of the benthic community would require modifications to this protocol. For example, adding at least 5lbs of weight to the ponar would help ensure it aligns correctly in the water column for contact with the substrate. However, the small sample sizes from this grab may still be insufficient for a more in depth study of infauna, and warrant consideration of vacuum approaches with compressed air (although logistics for this method are significantly greater).

Fish Community

Fish sampling was conducted in all lagoons using both a beach seine and an experimental gill net.

The 37-m bag beach seine was used to sample fish at any location where beaches allowed for deployment (e.g., sandy with no protruding rocks). Reynolds set beach seines by anchoring one end on land and then having two-team members drag the net first perpendicular to the shore, and then back to the beach in a U pattern. We used a more common protocol of setting the net parallel and 20 m from shore, and then retrieving the net in a symmetrical manner with people drawing the net in with lines attached to the net's ends (per Robards et al., 1999). Fish were picked from the bag and net, identified, counted, measured, and returned to the water as quickly as possible. No fish were kept during this effort.

A 5-panel experimental gill net was used to collect larger, pelagic species. Each net consisted of 5 panels, each 25ft in length, for a total net length of 125ft. Stretch measurement of the individual panels were: 1 inch, 1.5 inch, 2 inch, 3 inch, and 4 inch. Nets were set for 1 hour at the central lagoon location of each lagoon, rather than as for Reynolds who set the nets perpendicular from shore, which would mirror habitats already sampled by the beach seine. Captured fish were identified and measured.

Implementation

Between July 21st and July 29th 2012, a four-person crew from Wildlife Conservation Society and National Park successfully utilized a Cessna 185 on floats to access Ikpek and Cowpack lagoons in Bering Land Bridge National Preserve, and Kotlik, Krusenstern, and Aqulaaq lagoons in Cape Krusenstern National Monument. Total flight time for the logistics necessary to transport personnel and gear to each of the lagoons (2 flights per lagoon for each of the deployment and retrieval) totaled 18.3 hours for the pilot (Eric Sieh), using a Cessna 185 on floats.

Over two days at each lagoon (one day at Aqalaaq Lagoon), we used a small inflatable boat equipped with a 9 horsepower motor to visit four long-term (Center, Outflow, Inflow, and Adjacent-to-the-Ocean stations) and three Random stations in each lagoon. At each station, we collected (or attempted to collect) data on physical water parameters (Sonde digital probe), chorophyll a (filtered samples and lab spectrographic analysis), benthic invertebrates (Ponar grab), nearshore fish (beach seine), pelagic fish (gillnet), and opportunistic observations of the avian community (Appendix 1).

While we completed our goals within the 9-day field-sampling period, we were relatively fortunate with weather, having no weather days to contend with. We also had perfect weather for Ikpek lagoon, which was very challenging to sample due to the extensive areas of shallow water that required long-periods of walking the boat. For a repeat of this protocol, we would highly recommend at least one more day be allotted for each site (i.e. 3 days per site). This would also facilitate additional time for additional beach seines and bird observations as well as cater to slower sampling in poorer conditions.

Below we briefly summarize the sampling layout and effort at each lagoon and then describe collective results for all lagoons.

Ikpek (7/21/2012 to 7/23/2012)

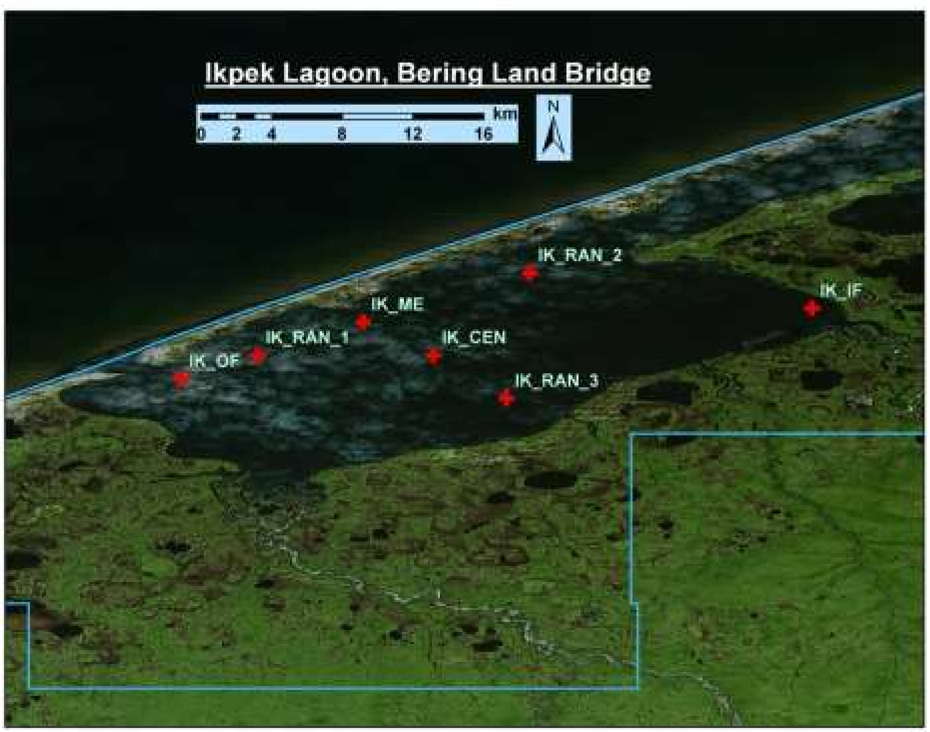

Figure 4. Ikpek Lagoon and Sampling Sites (RAN = Random, CEN = Central, OF = Outflow, ME = Marine Edge, IF = Inflow).

Ikpek is a large shallow lagoon connected to the ocean via a wide channel in the northwest corner (and again to the ocean to the northeast via a long narrow channel). We were dropped off and camped close to the RAN 1 sampling location. On the 22nd of July we needed 10 hours of work in perfect conditions (i.e., no wind and sunny) to complete sampling of almost the entire lagoon (two locations being completed the evening before). Much of lagoon was only about 30 cm in depth so water parameters at these shallow locations were taken mid-water column. In places, there were extended deeper areas, particularly in the center where we reverted to taking measurements at the target 50 cm depth.

Numerous *Rangifer tarandus* (several hundred on the beach on south side of outlet and some tens around camp) were always present during our two days. On the beach, numerous fresh bear tracks indicated their presence but we never saw a bear. We walked to a walrus carcass on shore about 4 miles north of camp.

Cowpack 7/23/2012 - 7/25/2012

Figure 5. Cowpack Lagoon and Sampling Sites (RAN = Random, CEN = Central, OF = Outflow, ME = Marine Edge, IF = Inflow).

Cowpack is a long, narrow lagoon with extensive shallows in the western end. We were dropped off and camped just east of the ME Sampling location. This lagoon is connected to the ocean via a channel in the northeast corner. Coastal areas were composed of extensive anoxic mud shallows (black stinky muds); we were unable to deploy beach seines along most of the sides of the lagoon, including the areas identified as parts of the Geographic Response Strategies. Anoxic muds were common throughout the lagoon (as evidenced by the prop-wash) except in an area close to the connection with the ocean in the northeast corner. Although chlorophyll a was not detected in much of the lagoon, filters were green on filtering. At the outflow, very compacted substrates precluding grab samples for benthic fauna.

Weather deteriorated during this survey with rain and westerly 25-knot winds after we finished on the first evening, pushing water up to the northeast corner of the lagoon (more pronounced than the lunar tide). A half-meter swell developed by 9 pm making boating and net handling difficult. However, the 2kg weights on either end of gill net were ample (net set perpendicular to wind).

On flying in, we observed a dead grey whale on the beach just north of Shishmaref (informed Gay Sheffield – Alaska Sea Grant for stranding data) and a dead walrus on the beach just south of the entrance channel. Numerous bear tracks were observed on the beach, but no bears observed. Over 1000 shorebirds and seabirds were congregated at the entrance to the lagoon – terns regularly carryed forage fish past our camp.

Kotlik Lagoon 7/25/2012 – 7/27/2012

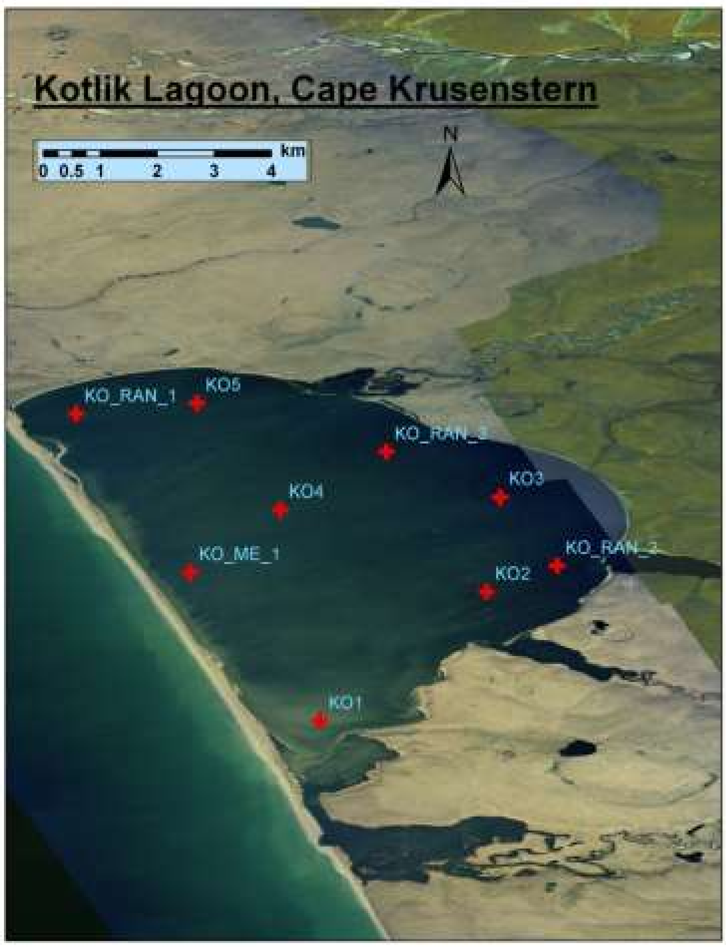

Figure 6. Kotlik Lagoon and Sampling Sites (RAN = Random, CEN = Central, OF = Outflow, ME = Marine Edge, IF = Inflow).

Kotlik was consistently deeper than the lagoons sampled in Bering Land Bridge facilitating travel in the inflatable boat. We were dropped off and camped by the RAN 1 sampling location. Kotlik Lagoon is connected to the ocean via an entry channel to the south of the main lagoon body. During our stay we sampled the RAN 1 site's Nephelometric Turbidity Units (NTUs) on 7/26/2012 as part of the regular protocol at 20.2 NTUs. As on other days, afternoon and night winds increased to 25 knots (on this occasion, from the southeast with intermittent rain), churning the lagoon with a 0.5 m chop. On the 27th of

July, we measured 49.5 NTUs, over double the previous day's reading. We observed a grizzly bear on the beach about 100 m to the north of camp.

Krusenstern Lagoon: 7/27/2012-7/28/2012

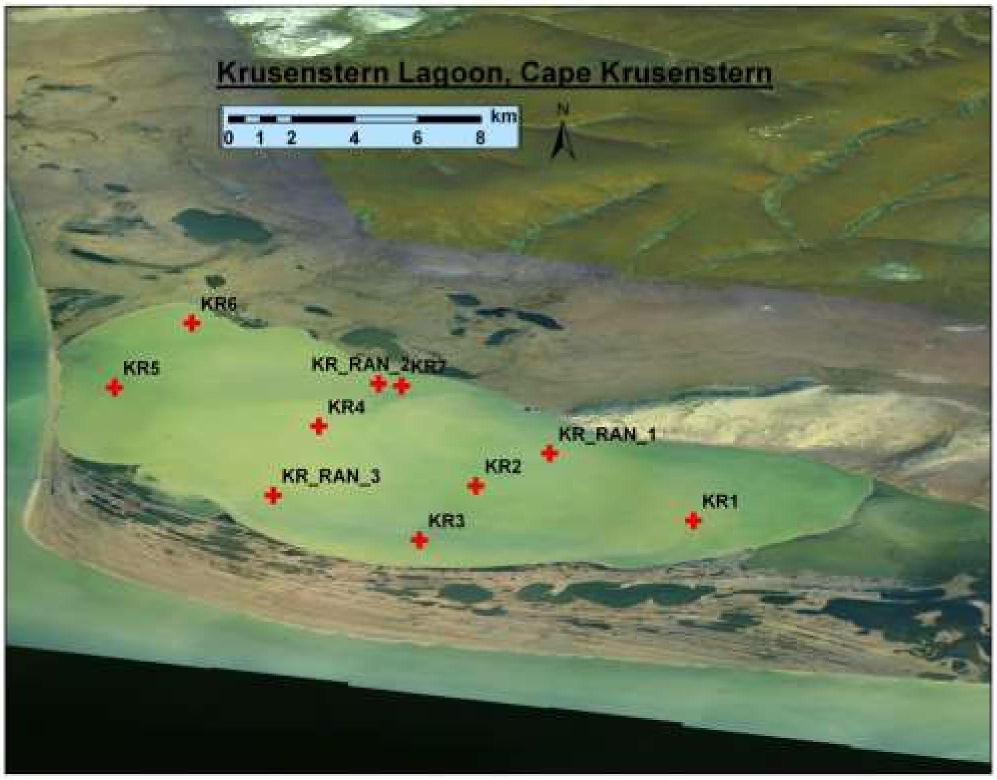

Figure 7. Krusenstern Lagoon and Sampling Sites (RAN = Random, CEN = Central, OF = Outflow, ME = Marine Edge, IF = Inflow).

Cape Krusenstern is the largest of the lagoons that we sampled. We were dropped off and camped close to the RAN 2 sample location on a small peninsula. While Krusenstern Lagoon was higher in NTU, it had a Total Suspended Solids (TSS) that was lower than all the other lagoons. While beyond the scope of our study, we expect that suspended diatoms are the primary TSS component in Krusenstern; as compared with the other lagoons where actual sediment may have been suspended (which would be heavier). All chlorophyll samples were very slow to pump (similar to Kotlik) compared to the BELA sites. At Krusenstern, we couldn't even see the propeller of the boat at times, supportive of the turbidity results. There is a lot of opportunity to beach seine on north side of lagoon, although unfortunately the winds were too high for good seining when we were there. Gill net weights were adequate again, but we would recommend adding streamers to the small tube floats (1 foot by 6 inches) as they were dragged under and hard to find.

Again, afternoon weather came in, this time from the southwest with a half-meter swell and rain by evening and up to 1 m swells in places by the time we finished. We would recommend the use of dry suites in future as there is a lot of spray, particularly in the small boat. Dry suits would also benefit safety in this lagoon that despite its size produced some unpleasant (potentially dangerous) conditions for a small boat.

Akulaaq Lagoon: 7/29/2012

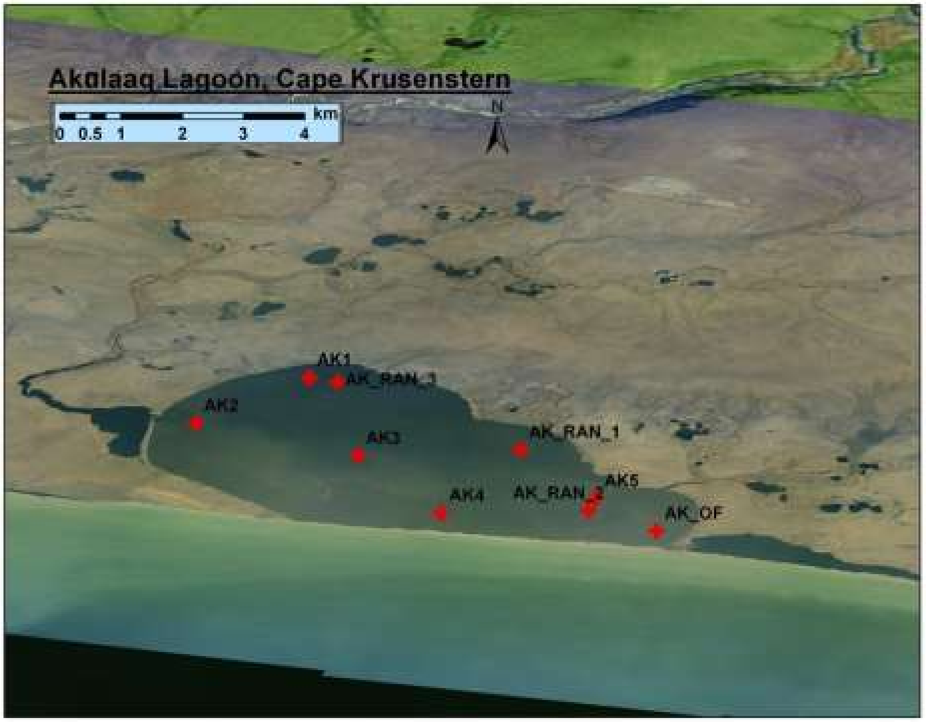

Figure 8. Akulaaq Lagoon and Sampling Sites (RAN = Random, CEN = Central, OF = Outflow, ME = Marine Edge, IF = Inflow).

Akulaaq is a relatively small lagoon. We were dropped off by the AK2 sample location, but did not camp overnight. The lagoon was not open to the ocean during our visit, with the outlet channel tapering out before reaching the ocean just south of the AK-OF sample location. Winds from the west would likely push water from the lagoon into the ocean and an onshore wind would likely do the reverse. We used the small lagoon just west of the AK2 sample location for take-off and landing for our plane support due to the heavy chop on the main lagoon (the easterly wind had the full fetch of this lagoon to build waves, but the small lagoon to the west was largely unaffected).

Overall Results

Below we briefly present summary results of the 2012 field effort. Raw data is included in the associated database d with ARCN at National Park Service in Fairbanks, Alaska (Metadata in Appendix 2).

Physical data suggested significant differences between lagoons, particularly with respect to salinity and turbidity (Table 3). The two Bering Land Bridge National Preserve lagoons were marine-influenced, as well as Kotlik in Cape Krusenstern National Monument. In contrast, Krusenstern and Aqulaaq lagoons were almost fresh water in nature. Turbidity in the Bering Land Bridge National Preserve lagoons was very low compared to those in Cape Krusenstern. We also observed profound variation in the turbidity of the latter lagoons in relation to wind that could double NTU readings in a few hours as the soft sediments become resuspended (see description of Kotkik sampling in previous section). The general patterns of physical conditions in lagoons are summarized in Table 1, and archived in the NPS database.

Table 3. Mean physical water parameters for the seven sample sites in each lagoon in July 2012.

Lagoon	Temperature °C	Dissolved O_2 (mg/l)	pH	Conductivity mS/cm	Salinity	NTU
Kotlik	12.39	10.93	8.84	28.50	17.61	41.89
Krusenstern	12.58	12.71	9.77	7.29	4.03	56.90
Aqulaaq	12.29	11.60	8.87	7.99	4.03	35.90
Cowpack	14.74	11.22	9.12	32.89	20.65	2.83
Ikpek	13.67	12.79	9.20	35.62	22.53	1.37

We assessed chlorophyll a using filtration in the field and spectroscopy by a commercial laboratory (Table 4). Most samples, at the time of our sampling, had chlorophyll a levels that were below detection limits (Table 4). Krusenstern was clearly the most biologically active lagoon in this July sampling as far as primary productivity. Aqulaaq and Cowpack were the only other two lagoons where we even detected chorophyll a, and for these two lagoons, only at the freshwater inflow sampling location.

As discussed in the implementation, the petite ponar grab was unable to collect repeatable samples at most sites, and often was unable to collect any sample at all. Consequently, we noted the key taxa observed in any sample collected, but did not attempt to quantify this by area. In future, a heavier grab (perhaps by weighting the current grab) and more comprehensive sampling protocol would need to be developed for better quantification of benthic invertebrates (Table 5).

Of the 24 species of fish that have been identified in the NPS unit lagoons, we caught 9 during 2012. Cape Krusentstern and Kotlik Lagoons were the most species rich of the lagoons we sampled (Table 6).

Future Collaboration Opportunities

Kevin Boswell and colleagues are conducting a North Pacific Research Board (NPRB) funded project: "Arctic coastal ecosystems: Evaluating the functional role and connectivity of lagoon and nearshore habitats." Their work is fundamental, as marine ecosystem research in the US Arctic has overlooked barrier-island lagoon and nearshore systems, despite the importance for subsistence fisheries and foraging habitat for protected marine mammals, seabirds, waterfowl and shorebirds. Their work in the Barrow/Wainwright area is the most active comparative coastal lagoon project in Arctic Alaska.

Table 4. Mean Chlorophyll a concentrations at the four fixed and three random sampling sites in each lagoon during July 2012. In general order of inflow to outflow

Lagoon	Sampling Station	Mean Chlorophyll a (mg/m3)	SD
Kotlik	Inflow	<0.20	0.00
	Central	<0.20	0.00
	Marine Edge	<0.20	0.00
	RAN1	<0.20	0.00
	RAN2	<0.20	0.00
	RAN3	<0.20	0.00
	Outflow	<0.20	0.00
Krusenstern	Inflow	25.33	3.06
	Central	23.67	5.86
	Marine Edge	37.33	2.52
	RAN1	33.33	2.08
	RAN2	30.33	1.53
	RAN3	23.67	0.58
	Outflow	38.67	0.58
Aqulaaq	Inflow	9.97	0.96
	Central	<0.20	0.00
	Marine Edge	<0.20	0.00
	RAN1	<0.20	0.00
	RAN2	<0.20	0.00
	RAN3	<0.20	0.00
	Outflow	<0.20	0.00
Cowpack	Inflow	8.83	1.68
	Central	<0.20	0.00
	Marine Edge	<0.20	0.00
	RAN1	<0.20	0.00
	RAN2	<0.20	0.00
	RAN3	<0.20	0.00
	Outflow	<0.20	0.00
Ikpek	Inflow	<0.20	0.00
	Central	<0.20	0.00
	Marine Edge	<0.20	0.00
	RAN1	<0.20	0.00
	RAN2	<0.20	0.00
	RAN3	<0.20	0.00
	Outflow	<0.20	0.00

Table 5. Invertebrate Species Inventory for Kotzebue Sound Lagoons based on four sampling periods since 1979[3]

			Cape Krusenstern[1]					Bering Land Bridge[1]	
Family	*Latin Name*	Common Name	Akulaaq	Imik	Kotlik	Krusenstern	Sisualik	Cowpack	Ikpek
	C. septemspinosa	Sand Shrimp					1		4
	Crangon Spp	Unidentified Crangon Shrimp	2				2	4	
	Mysid Spp.	Unidentified Mysid Shrimp				2	2		
	Macoma Spp	Clam[2]	2, 4	2	2, 4	2	2	4	4
	Mytilus Spp.	Mussel			2, 4				
		Polychaete	2			2, 4	2		4
		Tunicate						4	
		Chironomid Larvae	2	2	3	2	2		
		Isopod	2	2					
		Amphipod				2	2		4

[1]For each lagoon presence is denoted by **1** (Raymond et al., 1984), **2** (Reynolds et al., 2005), **3** (Reynolds, 2012), **4** (This report).

[2]*Macoma balthica* are reported by Dames and Moore (1983) for Red Dog study lagoons (just north of the National Park Service Cape Krusenstern unit).

[3]Additional invertebrate data is available in Erikson (1983) for Port Lagoon in Cape Krusenstern National Preserve, but have not been compiled into the NPS database yet.

Table 6. Fish species inventory for Kotzebue Sound lagoons (Note data represents vastly different fishing efforts, both within and between sampling periods, and not all lagoons were sampled in all sampling periods. Data should be used as the basis for inventory efforts, rather than inter-lagoon or temporal comparisons of composition or abundance).

					Cape Krusenstern[1]					Bering Land Bridge[1]	
Family	*Latin Name*	Common Name	Ipiavik	Port	Akulaaq	Imik[3]	Kotlik	Krusenstern	Sisualik	Cowpack	Ikpek
Clupeidae	*Clupea pallasii*	Pacific herring					3,5	4,5	1,3	5	
Umbridae	*Dallia pectoralis*	Alaska blackfish			3						
Osmerideae	*Mallotus villosus*	Capelin					5	5		5	
	Osmerus mordax	Rainbow smelt	2					3			
		Unidentified smelt							1,3		
Salmonidae	*Coregonus laurettae*	Bering cisco			3		5	3	3		
	C. nasus	Broad whitefish			3			3			
	C. pidschian	Humpback whitefish	2[4]		3		3	3,4,5	3		
		Unidentified whitefish							1		
	C. sardinella	Least cisco			3			3,4	3		
		Unidentified cisco							1		
	Stenodus leucichthys	Inconnu						1,3,4	3		
	Thymallus arcticus	Arctic grayling	2					3			
	Oncorhynchus gorbuscha	Pink salmon	2								
	O. keta	Chum salmon							1,3		
	Salvenlinus alpinus	Arctic char	2								
	S. malma	Dolly Varden					3				
Gadidae	*Eleginus gracilis*	Saffron cod	2				5		1,3		
Gasterosteidae	*Gasterosteus aculeatus*	Threespine stickleback						3,4	3		
	Pungitius pungitius	Ninespine stickleback	2	2			3,5	3,4,5	1,3		
Cottidae	*Cottus cognatus*	Slimy sculpin	2								
	Megalocottus platycephalus	Belligerent sculpin					3				
	Myoxocephalus quadricornis	Fourhorn sculpin	2		3		3,5		3		
		Unidentified sculpin							1		
Pleuronectidae	*Limanda aspera*	Yellowfin sole							3		
	Platichthys stellatus	Starry flounder	2				5	3,5	1,3		
	Pleuronectes glacialis	Arctic flounder							3		
	Pleuronectes quadrituberculatus	Alaska plaice					5			5	5
		Unidentified flatfish			3[2]				1		
TOTAL SPP.					**7**	**0**	**11**	**12**	**14**	**3**	**1**

[1]For each lagoon, presence is denoted by **1** (1979/1980 data - Raymond et al. 1984); **2** (1982/1983 data – Blaylock and Houghton, 1983); **3** (2003/2004 data – Reynolds, 2012); **4** (2009 data – Reynolds and Clough, 2010); **5** (2012 data – This report).
[2]Reynolds (2012) and Reynolds et al. (2005) indicate catches of unidentified Lepidopsetta spp. However, this is out of range for the genus so I classed more broadly as unidentified flatfish.
[3]Imik was only been sampled with a single gill net set on one occasion (catching no fish; Reynolds, 2012).
[4]1982 sampling effort.

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Appendix 1. Avian Species Inventory for Southern Chukchi Sea Lagoons based on opportunistic observations during field sampling 2012. Data table based on Robards and Shaw (unpublished data) documenting a full species inventory for coastal avifauna from Wales to Point Hope.

		Cape Krusenstern					**Bering Land Bridge**	
Common Name	**Scientific Name**	**Akulaaq**	**Imik**	**Kotlik**	**Krusenstern**	**Sisualik**	**Cowpack**	**Ikpek**
Greater White-fronted Goose	*Anser albifrons*							
Emperor Goose	*Chen canagica*						Medium	
Snow Goose	*Chen caerulescens*							
Brant	*Branta bernicla*				Medium		Medium	
Cackling Goose	*Branta hutchinsii*							
Canada Goose	*Branta canadensis*							
Trumpeter Swan	*Cygnus buccinator*							
Tundra Swan	*Cygnus columbianus*			Low	Low			Low
Whooper Swan	*Cygnus cygnus*							
Gadwall	*Anas strepera*							
Eurasian Wigeon	*Anas penelope*							
American Wigeon	*Anas americana*							
Mallard	*Anas platyrhynchos*							
Northern Shoveler	*Anas clypeata*							
Northern Pintail	*Anas acuta*						Low	
Green-winged Teal	*Anas crecca*							
Blue-winged Teal	*Anas discors*							
Canvasback	*Aythya valisineria*							
Redhead	*Aythya americana*							
Ring-necked Duck	*Aythya collaris*							
Greater Scaup	*Aythya marila*			Medium	Medium			
Lesser Scaup	*Aythya affinis*							
Steller's Eider	*Polysticta stelleri*							
Spectacled Eider	*Somateria fischeri*							
King Eider	*Somateria spectabilis*							
Common Eider	*Somateria mollissima*						Medium	Medium*
Harlequin Duck	*Histrionicus histrionicus*	Low			Low		Medium	
Surf Scoter	*Melanitta perspicillata*							
White-winged Scoter	*Melanitta fusca*							
Black Scoter	*Melanitta americana*							

Appendix 1. Avian Species Inventory for Southern Chukchi Sea Lagoons based on opportunistic observations during field sampling 2012. Data table based on Robards and Shaw (unpublished data) documenting a full species inventory for coastal avifauna from Wales to Point Hope.

		Cape Krusenstern					Bering Land Bridge	
Common Name	**Scientific Name**	**Akulaaq**	**Imik**	**Kotlik**	**Krusenstern**	**Sisualik**	**Cowpack**	**Ikpek**
Long-tailed Duck	*Clangula hyemalis*						Very High	Medium
Bufflehead	*Bucephala albeola*							
Common Goldeneye	*Bucephala clangula*							
Barrow's Goldeneye	*Bucephala islandica*							
Common Merganser	*Mergus merganser*							
Red-breasted Merganser	*Mergus serrator*							
Spruce Grouse	*Falcipennis canadensis*							
Willow Ptarmigan	*Lagopus lagopus*							
Rock Ptarmigan	*Lagopus muta*							
Red-throated Loon	*Gavia stellata*							Low
Arctic Loon	*Gavia arctica*							
Pacific Loon	*Gavia pacifica*			Low	Low		Medium*	Low
Common Loon	*Gavia immer*							
Yellow-billed Loon	*Gavia adamsii*						Low	Low
Horned Grebe	*Podiceps auritus*							
Red-necked Grebe	*Podiceps grisegena*							
Northern Fulmar	*Fulmarus glacialis*							
Short-tailed Shearwater	*Puffinus tenuirostris*							
Fork-tailed Storm-Petrel	*Oceanodroma furcata*							
Brandt's Cormorant	*Phalacrocorax penicillatus*							
Pelagic Cormorant	*Phalacrocorax pelagicus*							
Osprey	*Pandion haliaetus*							
Bald Eagle	*Haliaeetus leucocephalus*							
Northern Harrier	*Circus cyaneus*							
Sharp-shinned Hawk	*Accipiter striatus*							
Northern Goshawk	*Accipiter gentilis*							
Red-tailed Hawk	*Buteo jamaicensis*							
Rough-legged Hawk	*Buteo lagopus*							
Golden Eagle	*Aquila chrysaetos*							
American Kestrel	*Falco sparverius*							
Merlin	*Falco columbarius*							

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		Cape Krusenstern					**Bering Land Bridge**	
Common Name	**Scientific Name**	**Akulaaq**	**Imik**	**Kotlik**	**Krusenstern**	**Sisualik**	**Cowpack**	**Ikpek**
Gyrfalcon	*Falco rusticolus*							
Peregrine Falcon	*Falco peregrinus*							
Sandhill Crane	*Grus canadensis*						Low	Low*
Black-bellied Plover	*Pluvialis squatarola*							
American Golden-Plover	*Pluvialis dominica*							
Pacific Golden-Plover	*Pluvialis fulva*							
Lesser Sand Plover	*Charadrius mongolu*							
Semipalmated Plover	*Charadrius semipalmatus*							
Spotted Sandpiper	*Actitis macularius*							
Solitary Sandpiper	*Tringa solitaria*							
Wandering Tattler	*Tringa incana*							
Lesser Yellowlegs	*Tringa flavipes*							
Upland Sandpiper	*Bartramia longicauda*							
Eskimo Curlew	*Numenius borealis*							
Whimbrel	*Numenius phaeopus*						Low	
Bristle-thighed Curlew	*Numenius tahitiensis*							
Hudsonian Godwit	*Limosa haemastica*							
Bar-tailed Godwit	*Limosa lapponica*							
Marbled Godwit	*Limosa fedoa*							
Ruddy Turnstone	*Arenaria interpres*							
Black Turnstone	*Arenaria melanocephala*							
Surfbird	*Aphriza virgata*							
Red Knot	*Calidris canutus*							
Sanderling	*Calidris alba*							
Semipalmated Sandpiper	*Calidris pusilla*						High	Low
Western Sandpiper	*Calidris mauri*						Low	Medium*
Red-necked Stint	*Calidris ruficollis*							
Least Sandpiper	*Calidris minutilla*	Medium		Medium				Medium
Baird's Sandpiper	*Calidris bairdii*							
Pectoral Sandpiper	*Calidris melanotos*							
Sharp-tailed Sandpiper	*Calidris acuminata*							

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		Cape Krusenstern					Bering Land Bridge	
Common Name	**Scientific Name**	**Akulaaq**	**Imik**	**Kotlik**	**Krusenstern**	**Sisualik**	**Cowpack**	**Ikpek**
Rock Sandpiper	*Calidris ptilocnemis*							
Curlew Sandpiper	*Calidris ferruginea*							
Dunlin	*Calidris alpina*	Low					High	
Stilt Sandpiper	*Calidris himantopus*							
Spoon-billed Sandpiper	*Eurynorhynchus pygmeus*							
Buff-breasted Sandpiper	*Tryngites subruficollis*							
Ruff	*Philomachus pugnax*							
Long-billed Dowitcher	*Limnodromus scolopaceus*							
Wilson's Snipe	*Gallinago delicata*							
Red-necked Phalarope	*Phalaropus lobatus*							
Red Phalarope	*Phalaropus fulicarius*							
Black-legged Kittiwake	*Rissa tridactyla*						High	
Red-legged Kittiwake	*Rissa brevirostris*							
Ivory Gull	*Pagophila eburnea*							
Sabine's Gull	*Xema sabini*							
Bonaparte's Gull	*Chroicocephalus philadelphia*						Medium	
Ross's Gull	*Rhodostethia rosea*							
Mew Gull	*Larus canus*							
Herring Gull	*Larus argentatus*							
Iceland Gull	*Larus glaucoides*							
Slaty-backed Gull	*Larus schistisagus*							
Glaucous-winged Gull	*Larus glaucescens*							
Glaucous Gull	*Larus hyperboreus*	Low		Low			Medium	Medium
Aleutian Tern	*Onychoprion aleuticus*							
Arctic Tern	*Sterna paradisaea*			Medium	Low		Medium	Low
Pomarine Jaeger	*Stercorarius pomarinus*							
Parasitic Jaeger	*Stercorarius parasiticus*						Low	Low
Long-tailed Jaeger	*Stercorarius longicaudus*							Low
Common Murre	*Uria aalge*							
Thick-billed Murre	*Uria lomvia*							
Black Guillemot	*Cepphus grylle*							

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		Cape Krusenstern					Bering Land Bridge	
Common Name	**Scientific Name**	**Akulaaq**	**Imik**	**Kotlik**	**Krusenstern**	**Sisualik**	**Cowpack**	**Ikpek**
Pigeon Guillemot	*Cepphus columba*							
Kittlitz's Murrelet	*Brachyramphus brevirostris*							
Parakeet Auklet	*Aethia psittacula*							
Least Auklet	*Aethia pusilla*							
Crested Auklet	*Aethia cristatella*							
Horned Puffin	*Fratercula corniculata*							
Tufted Puffin	*Fratercula cirrhata*							
Great Horned Owl	*Bubo virginianus*							
Snowy Owl	*Bubo scandiacus*							
Northern Hawk Owl	*Surnia ulula*							
Great Gray Owl	*Strix nebulosa*							
Short-eared Owl	*Asio flammeus*							
Boreal Owl	*Aegolius funereus*							
Belted Kingfisher	*Megaceryle alcyon*							
Downy Woodpecker	*Picoides pubescens*							
American Three-toed Woodpecker	*Picoides dorsalis*							
Northern Flicker	*Colaptes auratus*							
Northern Shrike	*Lanius excubitor*							
Olive-sided Flycatcher	*Contopus cooperi*							
Alder Flycatcher	*Empidonax alnorum*							
Say's Phoebe	*Sayornis saya*							
Eastern Kingbird	*Tyrannus tyrannus*							
Gray Jay	*Perisoreus canadensis*							
Clark's Nutcracker	*Nucifraga columbiana*							
Black-billed Magpie	*Pica hudsonia*							
Common Raven	*Corvus corax*							
Horned Lark	*Eremophila alpestris*							
Tree Swallow	*Tachycineta bicolor*							
Violet-green Swallow	*Tachycineta thalassina*							
Bank Swallow	*Riparia riparia*							
Cliff Swallow	*Petrochelidon pyrrhonota*							

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		Cape Krusenstern					Bering Land Bridge	
Common Name	**Scientific Name**	**Akulaaq**	**Imik**	**Kotlik**	**Krusenstern**	**Sisualik**	**Cowpack**	**Ikpek**
Barn Swallow	*Hirundo rustica*							
Black-capped Chickadee	*Poecile atricapillus*							
Boreal Chickadee	*Poecile hudsonicus*							
Gray-headed Chickadee	*Poecile cinctu*							
American Dipper	*Cinclus mexicanus*							
Ruby-crowned Kinglet	*Regulus calendula*							
Arctic Warbler	*Phylloscopus borealis*							
Bluethroat	*Luscinia svecica*							
Northern Wheatear	*Oenanthe oenanthe*							
Mountain Bluebird	*Sialia currucoides*							
Townsend's Solitaire	*Myadestes townsendi*							
Gray-cheeked Thrush	*Catharus minimus*							
American Robin	*Turdus migratorius*							
Varied Thrush	*Ixoreus naevius*							
European Starling	*Sturnus vulgaris*							
Eastern Yellow Wagtail	*Motacilla tschutschensis*							
White Wagtail	*Motacilla alba*							
American Pipit	*Anthus rubescens*							
Red-throated Pipit	*Anthus cervinus*							
Bohemian Waxwing	*Bombycilla garrulus*							
Lapland Longspur	*Calcarius lapponicus*							Low*
Smith's Longspur	*Calcarius pictus*							
Snow Bunting	*Plectrophenax nivalis*							
McKay's Bunting	*Plectrophenax hyperboreus*							
Northern Waterthrush	*Parkesia noveboracensis*							
Orange-crowned Warbler	*Oreothlypis celata*							
Yellow Warbler	*Setophaga petechia*							
Blackpoll Warbler	*Setophaga striata*							
Yellow-rumped Warbler	*Setophaga coronata*							
Wilson's Warbler	*Cardellina pusilla*							
American Tree Sparrow	*Spizella arborea*							

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		Cape Krusenstern					**Bering Land Bridge**	
Common Name	**Scientific Name**	**Akulaaq**	**Imik**	**Kotlik**	**Krusenstern**	**Sisualik**	**Cowpack**	**Ikpek**
Savannah Sparrow	*Passerculus sandwichensis*	Low						
Fox Sparrow	*Passerella iliaca*							
Lincoln's Sparrow	*Melospiza lincolnii*							
White-crowned Sparrow	*Zonotrichia leucophrys*							
Golden-crowned Sparrow	*Zonotrichia atricapilla*							
Dark-eyed Junco	*Junco hyemalis*							
Red-winged Blackbird	*Agelaius phoeniceus*							
Rusty Blackbird	*Euphagus carolinus*							
Common Grackle	*Quiscalus quiscula*							
Brambling	*Fringilla montifringilla*							
Gray-crowned Rosy-Finch	*Leucosticte tephrocotis*							
Pine Grosbeak	*Pinicola enucleator*							
White-winged Crossbill	*Loxia leucoptera*							
Common Redpoll	*Acanthis flammea*							
Hoary Redpoll	*Acanthis hornemanni*							
Hawfinch	*Coccothraustes coccothraustes*							

Seen at low (1-9 birds), medium (10-99 birds), high (100-999) or very high (>999) birds per sighting (including young).
*Confirmed as nesting or with flightless young denoted with

Appendix 2. Metadata for Excel Archive

Tab 1: Sample Locations
Includes all sites sampled by Melinda Reynolds and Martin Robards.

Field 1: Park = National Park Unit
Field 2: ID = Location Code
Field 3: Latitude
Field 4: Longitude
Field 5: Source

Tab 2: Reynolds Thesis Sampling Dates
No sampling dates are provided in the thesis. These data provided by Melinda Reynolds (*pers. comm.*).

Field 1: Sampling Period = Per thesis bins for data
Field 2: Month
Field 3: Lagoon
Field 4: Sampling Dates = In some cases only a window of time available.

Tab 3: Reynolds Physio Data
Physical water attributes for Melinda Reynolds' sampling efforts in 2003/2004 and 2009.

Field 1: Date
Field 2: Lagoon
Field 3: Station = Location (See Tab 1)
Field 4: Salinity
Field 5: Dissolved Oxygen
Field 6: Water Temperature
Field 7: Dissolved Oxygen (D.O.)
Field 8: Conductivity (Cond.)
Field 9: pH
Field 10: Water Depth
Field 11: Source

Tab 4: Robards Physical Data
All data from sonde (field readings) and time of filtering for Chorophyll samples (for lab analysis). Note Chlorophyll samples taken at same time as sonde deployment.

Field 1: Lagoon
Field 2: Site = Location (see Tab 1)
Field 3: Depth = Measured with hand-held depth sonar
Field 4: Date
Field 5: Time
Field 6: Chlorophyll filtered (time in the field)
Field 7: Temperature
Field 8: MicroSiemens
Field 9: Salinity

Field 10: Depth = measured with sonde
Field 11: pH
Field 12: PAR (aberrant readings in 2012)
Field 13: NTU
Field 14: Chlorophyll (aberrant readings in 2012)
Field 15: Dissolved oxygen (%)
Field 16: Dissolved oxygen (mg/l)
Field 17: TSS (samples taken for Total Suspended Solids – See Tab 11)
Field 18: Comments

Tab 5: Nutrients-pigments
Field 1: Date
Field 2: Month
Field 3: Year
Field 4: Lagoon
Field 5: Station or Sample
Field 6: Surface or Bottom Collection
Field 7: DKN (from Reynolds)
Field 8: DKN (from Reynolds)
Field 9: TKN (from Reynolds)
Field 10: TKN (from Reynolds)
Field 11: TKP (from Reynolds)
Field 12: TKP (from Reynolds)
Field 13: Average Chlorophyll a (ug/l)
Field 14: Chorophyll a (SD)
Field 15: Average Phaephytin (from Reynolds)
Field 16: Source
Field 17: Detection Limit for Chlorophyll a.

Tab 6: Robards_Lab Chl_Raw (Raw Laboratory Data for Chlorophyll analysis)
Field 1: Sample ID (lab assigned)
Field 2: ClientSample ID (lab assigned)
Field 3: Field ID and replicate (of 3) (per field protocol names)
Field 4: Site ID (location in lagoon – blind to replicate)
Field 5: Lagoon
Field 6: Depth (0 = surface)
Field 7: Matrix
Field 8: Collection Date and Time
Field 9: Chlorophyll a

Tab 7: Robards_Ponar
Field 1: Lagoon
Field 2: Site

Field 3: Depth
Field 4: Date
Field 5: Time
Field 6: Notes on Sample
Field 7: Taxa observered.

Tab 8: Beach Seines
Field 1: Date (needs completing from report)
Field 2: Month
Field 3: Lagoon
Field 4: Site
Field 5: Time
Field 6: Set number (replicate)
Field 7: Common Name
Field 8: Latin Name
Field 9: Catch (number caught)
Field 10: Archival Photograph
Field 11: Reporting (full details in which report).

Tab 9: Gill Nets
Field 1: Date
Field 2: Month
Field 3: Lagoon
Field 4: Site
Field 5: Set on Day
Field 6: Time into water
Field 7: Time out of water
Field 8: Soak time
Field 9: Fish (species)
Field 10: # fish (number caught)
Field 11: Fish observations and which mesh caught in.

Tab 10: Fish Data (Morphometrics etc)
Field 1: Sampling lead (Primary investigator)
Field 2: Date
Field 3: Month
Field 4: Time
Field 5: Lagoon
Field 6: Location ID (place in lagoon)
Field 7: Collection Method
Field 8: Common Name
Field 9: Scientific Name
Field 10: Total Length

Tab 11: TSS (Total Suspended Solids)
Field 1: Date

Field 2: Lagoon
Field 3: Field Site
Field 4: Initial Filter Weight
Field 5: Filtrate Volume
Field 6: Final Filter Weight
Field 7: Total Weight of TSS (mg)
Field 8: TSS (mg/l)